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Expanded-Mode Semiconductor Laser with Tapered-Rib Adiabatic-Following Fiber Coupler

G. A. Vawter, R. E. Smith, H. Hou, J. R. Wendt

Sandia National Laboratories, Albuquerque, NM 87185-0603, USA

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A new diode laser using a Tapered-Rib Adiabatic-Following Fiber Coupler to achieve 2D mode expansion and narrow, symmetric far-field emission without epitaxial regrowth or sharply-defined tips on tapered waveguides is presented.

DISCLAIMER

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Expanded-mode semiconductor lasers[1, 2] offer benefits of reduced far-field divergence as well as improved coupling efficiency and ease of alignment to optical fiber. We present a new diode laser using a Tapered-Rib Adiabatic-Following Fiber Coupler[3] (TRAFFiC) to achieve 2D mode expansion without epitaxial regrowth or sharply-defined tips on tapered waveguides. The TRAFFiC laser, Fig. (1), uses lateral tapering of a rib waveguide to adiabatically convert the rib mode to the fundamental mode of a larger underlying mesa guide. Progressive narrowing of the etched rib from 2 µm to 0.4 µm wide squeezes the optical mode out of the rib and down into the larger mesa waveguide thereby expanding the fundamental optical mode size. This is the first demonstration of a TRAFFiC mode expander in an active device.

The laser is a strained-quantum-well separate-confinement heterostructure type employing two $In_{0.20}Ga_{0.80}As$ quantum-well (QW) active layers within a $GaAs/Al_{0.1}Ga_{0.9}As$ double-heterostructure. The rib waveguide is etched in the cladding region above the QWs to define the active lasing section and 0.5-mm-long TRAFFiC coupler. The 10 µm-wide outer mesa and lower $Al_{0.4}Ga_{0.6}As$ cladding barrier layer provide confinement of the expanded optical mode within the 8-µm thick lower cladding. Overall length of the lasers is 1.25 mm of which 1 mm is contacted for electrical current injection.

Fabrication used two lithography and dry-etch steps. The tapered-rib waveguide was defined using electron-beam direct-write lithography but could be defined using optical methods. Pulsed threshold current of the TRAFFiC laser, Fig. (2), is 160 mA compared to 82 mA for the uniform 2-µm wide control. Output matches that of the control laser at the maximum tested current of 300 mA. This suggests that these first TRAFFiC lasers have increased optical losses or saturable absorption in regions of low injection current along the taper which might be reduced with optimized processing and electrical contacting. Near-field images, Fig.(3), show dramatic mode expansion. No evidence of high-order modes is seen at any tested current level. Measurements of 7° and 6° FWHM along the two principal axes of the far-field emission pattern support the conclusion that the TRAFFiC structure is functioning as expected. The only evident deviation from expected behavior is incomplete filling of the lower cladding caused by a slight refractive-index discontinuity (due to a doping increase) at the bottom edge of the mesa.

In conclusion, this TRAFFiC laser achieves a 2D expansion of the output mode by tapering the width of an etched rib using dimensions which are compatible with optical lithographic techniques. Stable fundamental mode operation with a narrow, 6° by 7° FWHM, far-field is observed well above lasing threshold. The TRAFFiC laser is suitable for use where low optical fiber coupling loss or low beam divergence are desired. Such applications include pump sources for Er^{+}-doped fiber amplifiers and optical range sensing.

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Figure 1: Representation of the TRAFFiC laser showing the tapered-rib upper cladding shape and the approximate form and size of the optical mode in the active gain section of the wide rib region (inset) and the expanded size and shape of the output optical mode at the cleaved end where the rib is most narrow.

Figure 2: Threshold characteristics of TRAFFiC and 2-μm wide control lasers. Data is for 1 μs pulses at 1 kHz repetition rate.

Figure 3: Contour plots of measured near-field emission intensity pattern of expanded-mode TRAFFiC laser and 2-μm-wide control laser. The back facet emission image of the TRAFFiC laser is indistinguishable from that of the control laser.

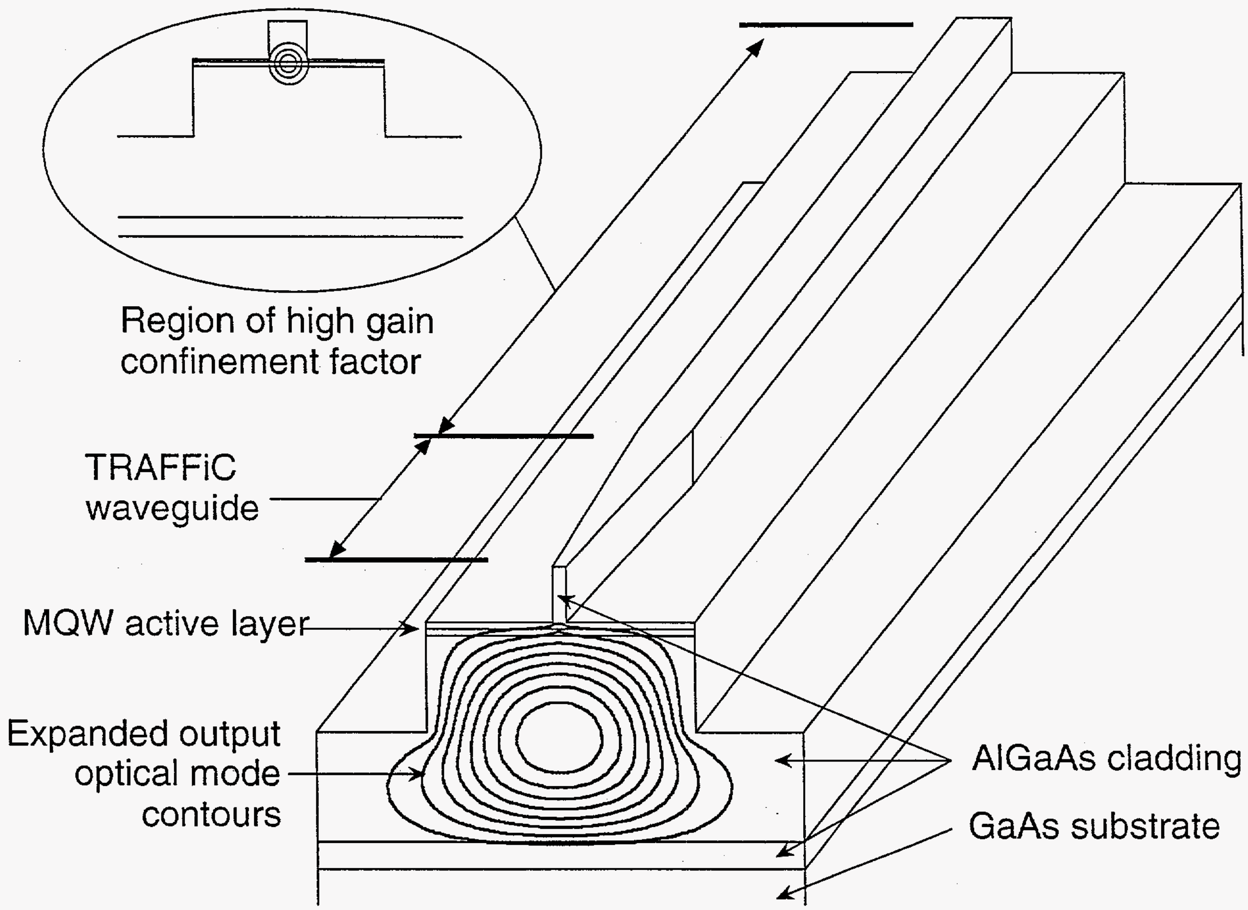
Region of high gain
confinement factor
TRAFFiC
waveguide
MQW active layer
Expanded output
optical mode
contours
AlGaAs cladding
GaAs substrate

Figure 1

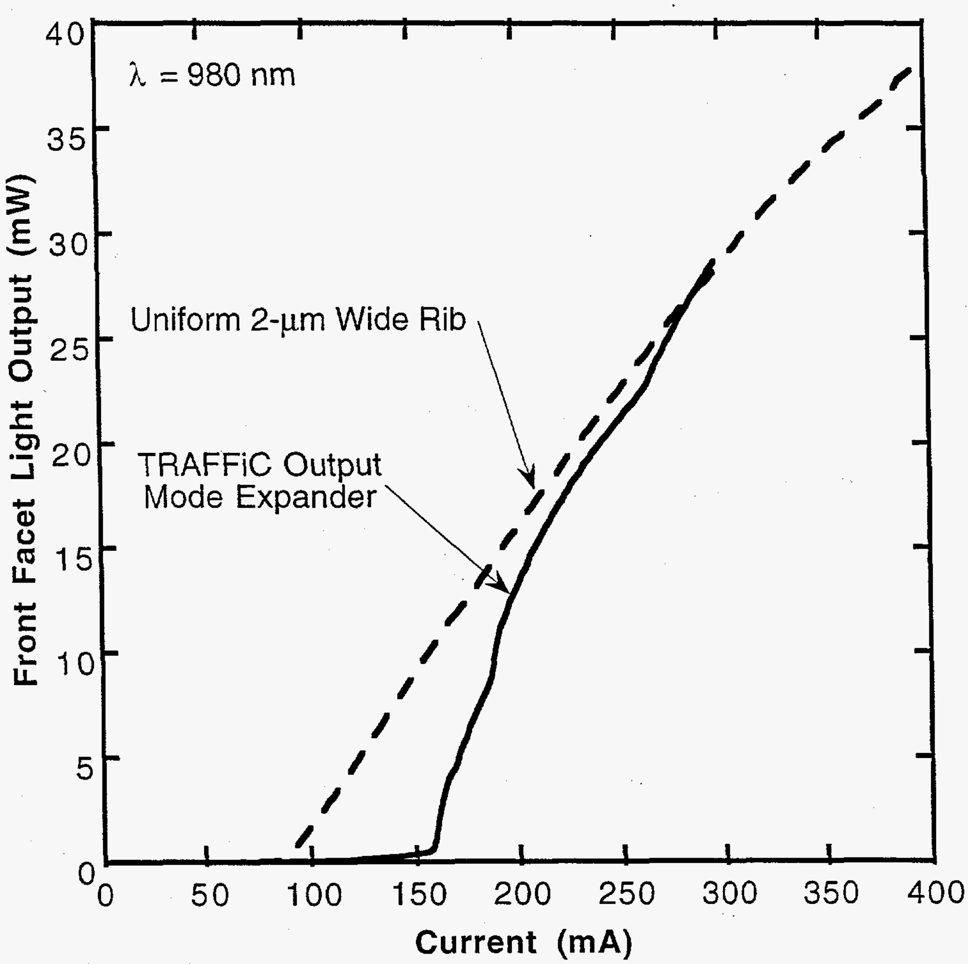
λ = 980 nm
Uniform 2-µm Wide Rib
TRAFFiC Output
Mode Expander
Front Facet Light Output (mW)
Current (mA)
0
5
10
15
20
25
30
35
40
0
50
100
150
200
250
300
350
400

Figure 2

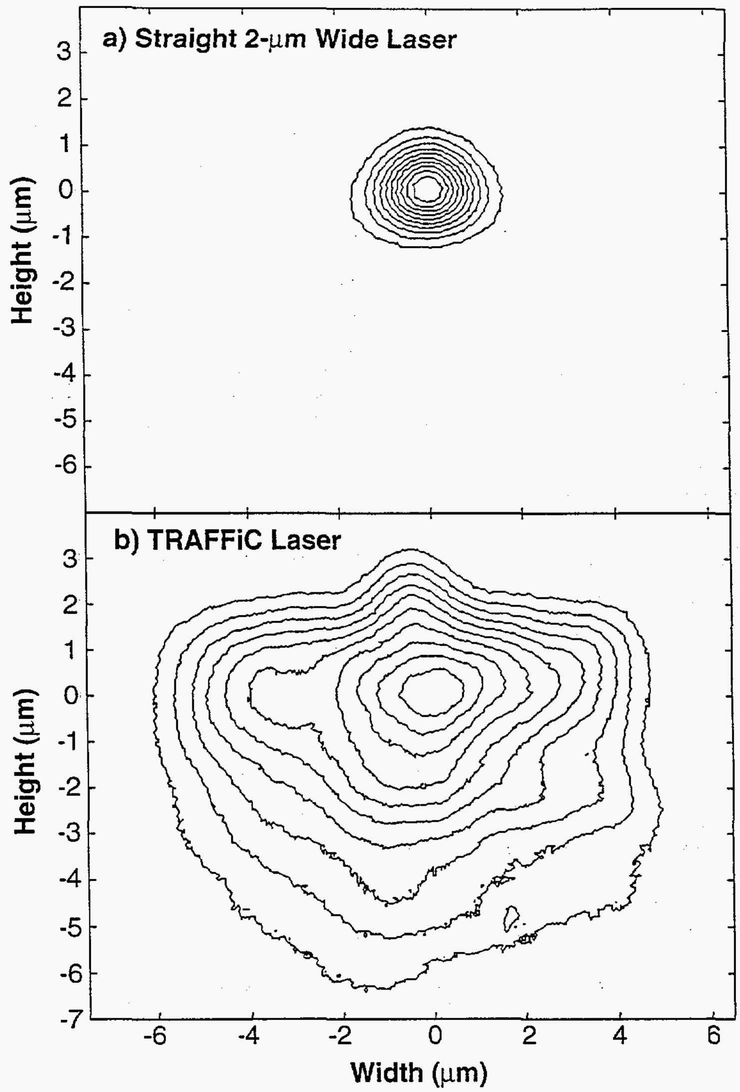
a) Straight 2-μm Wide Laser
b) TRAFFiC Laser
Height (μm)
Height (μm)
Width (μm)
3
2
1
0
-1
-2
-3
-4
-5
-6
-7
-6
-4
-2
0
2
4
6

Figure 3